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A.R.D.E. MEMORANDUM (MX) 80/59

Air-blast effectiveness of Continuous-Rod Warheads

K. J. Jarvis

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Fort Halstead.
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TO: Commanding Officer
US Army Ordnance Technical Intelligence Agency
Arlington Hall Station
Arlington 12, Virginia

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ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT

A.R.D.E. MEMORANDUM (MX) 80/59

Air-blast effectiveness of Continuous-Rod Warheads

K.J. Jarvis (X1)

Summary

Measurements have been made to determine the principal parameters describing the blast waves generated by the Blue Jay and Red Dean continuous-rod warheads. These are compared with similar measurements using unconfined explosive charges of the same geometric configuration and weight as those used in the warheads. From this data 'equivalent bare charge' weights are computed for the warheads and graphs presented showing the peak overpressure, positive impulse and positive duration, as functions of distance, that are to be expected for blast waves produced by these warheads.

Approved for issue:

L. Northcott, Principal Superintendent 'MX' Division

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1. INTRODUCTION

1.1 A series of trials were carried out during 1958 to test the lethality of 'second generation warheads' against loaded aircraft structures. During these trials Red Dean and Blue Jay continous-rod warheads were detonated at various stand-offs from an inverted B-29 wing which was loaded with weights to simulate flight stresses. The continuous-rod warhead which is designed, primarily, to be efficient in projecting the continuous-rod, produces a considerable blast effect and this must be considered when calculating the lethality envelope for a particular target. The parameters (peak pressure and positive impulse) describing the air blast potentialities of these warheads are thus of interest to the warhead designer and in damage assessment studies.

At the request of the Royal Aircraft Establishment a team from A.R.D.E. X.1 Branch participated in the firing trials of the C.R. warheads and made measurements of the blast produced by the warheads. It was requested that the resultant data should be presented in the form of an 'equivalent bare charge' weight for each warhead i.e. that weight of unconfined explosive which, over a range of distances, will give the same values of peak pressure and positive impulse to those observed from the warhead. This assumed that a unique value could be assigned to this parameter. This assumption is not strictly accurate but, as will be shown, the variations are sufficiently small that this approximation can be made for all practical purposes. Due to the peculiar geometry of the H.E. charge it was considered advisable to conduct certain supporting experiments. These entailed firing unconfined explosive charges of the same shape and weight as the H,E. charge of the warheads and measuring the blast produced by these charges.

From the results obtained 'equivalent bare charge' weights have been calculated. It is shown that no unique value can be ascribed to this parameter for the warheads considered. The equivalent bare charge weight varies with the distance from the warhead and on the criterion used which may be based on peak pressure or positive impulse levels. However, for the particular warheads under consideration here, it is found that the value varies slowly with distance and values based on either a criterion of peak pressure or positive impulse agree within experimental error. Hence, over the range of distances considered, an average 'equivalent bare charge' weight can be assigned to each warhead. Along with these values graphs of peak pressure vs distance, positive impulse vs distance and positive duration vs distance are presented for both warheads.

2. EXPERIMENTAL METHOD

2.1 Warhead Firings

The Red Dean and Blue Jay C.R. warheads have a total weight of 120 lbs. and 48 lbs. respectively and H.E. filling weights of 25.75 lbs. and 8.81 lbs. of RDX/TNT 60/40. They were initiated during the trials by a C.E. exploder pellet positioned at the charge centre and a No.33 electric detonator. Figure 1 shows the essential details of these warheads.

To determine the blast potential of a munition it has been the custom to fire the charge on the ground and record the peak pressure and positive impulse values over a fairly wide range of distances in the equatorial plane of the charge i.e. perpendicular to the charge axis. These conditions were appropriate to the operational use of the munitions in question i.e. H.E. bombs, against ground structures, the bomb usually being in a nearly vertical position when detonated. The C.R. warhead has been designed for the attack of airborne targets. The warhead is detonated under

free air conditions i.e. in the absence of any major blast reflecting surface. Also it may be orientated in any position relative to the target, although certain positions are favoured due to missile guidance. One such preferred orientation is that in which the warhead axis forms an angle of 45° with the horizontal and vertical planes of the target aircraft. This was the position adopted during the trials.

The rod is projected in the plane normal to the charge axis and a knowledge of the blast parameters in this plane was required. As it was not practicable to measure in this plane since the blast gauges would be destroyed by the expanding rods, the gauges were positioned at stations in a plane at an angle of 45° to the axis of the charge. This was a fragment-free zone and the pressure gauge signals were fairly free from spurious signals associated with the shock waves generated by fragments. In the Blue Jay firing the gauges were mounted in pairs equidistantly at ten feet from the charge centre. For the Red Dean firings, however, the gauges were mounted in pairs, but at four different distances in a plane at an angle of 45° to the axis of the charge. All the gauges used measured the hydrostatic or 'side-on' value of peak pressure and positive impulse and, in view of the small number of observations which could be made, were mounted in pairs to insure against a possible gauge or amplifier failure. Figures 3 -6 give general views and details of the field lay-outs used during the trials.

2.2 Bare charge experiments

It is well known that, although at large distances peak pressures and impulses from non-spherical charges do not differ greatly with different directions from the charge, this is not true close to the charge and considerable dependence on direction is expected. It was necessary therefore to carry out additional experiments using bare cylindrical charges, thus allowing the blast parameters in the equatorial plane to be compared with those in the 45° plane. Assuming a similar relationship held for the C.R. warhead, values for the equatorial plane of the C.R. warhead could then be computed from the warhead trials.

The bare charges, hereafter referred to as Red Dean bare charges, were provided by X.2 Branch A.R.D.E. and made by casting RDX/TNT 60/40 directly into a split perspex liner of the type used in the Red Dean warhead. After cooling the liner was removed. A brass tube was cast into the charge, along the axis, and the charge initiated by a C.E. pellet positioned in this tube at the charge centre and a No.8 Briska electric detonator. These charges were thus identical in every respect to the H.E. fillings of the Red Dean warhead. Since the H.E. fillings of the Blue Jay and Red Dean warheads have the same geometry it was sufficient to perform the experiments using the Red Dean bare charges only as the results of these could be scaled to a Blue Jay bare charge by using the normal bare charge scaling laws.

The Red Dean bare charges were supported on wooden posts 23' above ground level and four pairs of gauges mounted at the same height and at the same distances used during the warhead trials. Three rounds were fired with the charge axis perpendicular to the gauge line and three rounds with the charge axis at 45° to this. Details of the field layout are given in Figure 2.

2.3 Instrumentation

Type H.3[1] piezo-electric blast gauges (See Figure 7) were used throughout. These gauges employ X-cut quartz crystals as the pressure sensing element and have a sensitivity of approximately 100 $\mu\mu$ coulombs per p.s.i. The calibration consistency of these gauges is 1%.

The blast gauges were connected by co-axial cables to multi-channel cathode-ray-oscillographic equipment where the gauge signal was amplified and displayed on a C.R.T. Drum cameras were used to record the displacement of the C.R.T. beams as functions of time. An electrical sequence timer synchronized the firing of the charge with the recording equipment. This unit switched the C.R.T. beams on for the duration of one drum revolution and applied calibration signals a few milliseconds before the charge was detonated. In addition an ionization probe fitted to the charge was used to trigger a thyratron valve which provided a pulse to the amplifiers to indicate the instant of detonation. A photograph of typical recording equipment can be seen in Figure 8.

Measurements of wind speed and direction, barometric pressure and air temperature were recorded at the site for the day of each firing.

3. RESULTS AND DERIVED DATA

Each pressure-time curve was analysed and the values of peak pressure (p_s), positive impulse (I), positive duration (τ) and shock transit time (t) calculated. The mean value of each of these parameters and the standard deviation of this mean was determined for each of the charge-gauge distances used. Tabulated figures for these data are given in the Appendix to this memorandum. These tables show also the scaled values obtained by dividing all times and distances by the cube root of the charge weight ($W^{\frac{1}{3}}$).

The recorded pressure-time curves were generally of good quality although it was observed that some of those recorded at the first two gauge positions for bare charges fired normal to the gauge line exhibited erratic oscillations during the initial decay. In view of the small number of rounds available all records have been used in the assessment.

3.1 Determination of 'equivalent bare charge' weight

All weapons possess some form of casing. This may be thin in the case of bombs designed primarily for blast effects or thicker for munitions designed to produce optimum fragmentation or other characteristics. The presence of the case means that less of the total energy in the explosive charge is available to produce blast and this loss is characterised by a reduction in the level of positive impulse intensity and peak pressures at a given distance from the weapon.

It has been demonstrated [2.3.4] by experiments using bare and cased charges of similar shape and weight of explosive that a value of bare explosive W_e can be determined which over a range of distances will give approximately the same values of impulse to that observed from a cased charge of actual explosive weight W. This figure W_e is defined as the Impulse 'equivalent bare charge' weight. A pressure 'equivalent bare charge' weight may be similarly defined.

The mean scaled values of positive impulse and peak pressure measured at 45° to the axis of the Red Dean warheads and Red Dean bare charges have been plotted in Figures 9 and 10. Curves of best fit have been drawn by eye through the mean values. The height of the vertical line through each mean represents twice the standard deviation of the mean at that point. The effect of the case is immediately apparent from an inspection of the curves. It is further observed that over most of the range the curves are very nearly parallel.

The pressure 'equivalent bare charge' weight may be calculated directly from Figure 9. Applying the normal scaling laws the ratio of the value W_e to the actual explosive weight W is the cube of the ratio of the distances at which the pressure is identical on the two curves.

$$\text{Thus:}\quad \frac{W_e}{W} = \left| \frac{R/W^{\frac{1}{3}} \quad \text{Curve B}}{R/W^{\frac{1}{3}} \quad \text{Curve A}} \right|^3 \quad \text{for equal pressure}$$

Using large scale log-log paper, to permit better accuracy, the ratio of the distances for equal pressures was measured at five points and an average value of the ratio $\frac{W_e}{W}$ determined. The figures obtained are given in Table 1 below.

TABLE 1

Pressure Level	$R/W^{\frac{1}{3}}$ Curve B	$R/W^{\frac{1}{3}}$ Curve A	$\frac{W_e}{W}$
20	5.25	7.2	.386
16	5.9	8.1	.381
12	6.8	9.5	.375
9	8.2	11.1	.402
6	10.5	13.8	.442
		Mean value	.40

Hence, the 'equivalent bare charge' weight of the Red Dean warhead applying a criterion of peak pressure, is 10.3 lbs. of RDX/TNT 60/40 over the scaled distance range of five-fourteen feet from the charge centre.

A similar method was employed to calculate the 'impulse equivalent bare charge' weight. In this case as the impulse values are scaled by the factor $W^{\frac{1}{3}}$ the distance ratios are measured at the intersection of a line drawn at 45° to the ordinate scale.

$$\text{Thus}\quad \frac{W_e}{W} = \left| \frac{R/W^{\frac{1}{3}} \quad \text{Curve B}}{R/W^{\frac{1}{3}} \quad \text{Curve A}} \right|^3 \quad \text{for equal } I/W^{\frac{1}{3}}$$

The values obtained by this method are given in Table 2.

TABLE 2

Impulse Level	$R/W^{\frac{1}{3}}$ Curve B	$R/W^{\frac{1}{3}}$ Curve A	$\frac{W_e}{W}$
10.3	5.35	7.45	.365
8.95	6.4	8.9	.370
7.3	8.3	11.4	.391
6.1	10.25	13.9	.402
		Mean value	.38

The 'equivalent bare charge' weight of the Red Dean warhead using a criterion of positive impulse is 9.8 lbs. RDX/TNT 60/40 over the scaled distance range of five-fourteen feet.

It is considered that the difference between the values of $\frac{W_e}{W}$ calculated above according to the definitions peak pressure and positive impulse is within experimental error and therefore a mean value of 0.39, which gives an 'equivalent bare charge' weight of 10 lbs. RDX/TNT 60/40 probably represents the best estimate of the fraction of the explosive weight which is available to produce blast.

In an earlier paragraph it was stated that as the Red Dean and Blue Jay warheads possessed the same geometry it would be possible, using the normal scaling laws, to apply the results from the former to the latter. This statement may now be tested. The H.E. filling weight of the Blue Jay warhead is 8.81 lbs. RDX/TNT 60/40 hence the 'equivalent bare charge' weight is 8.81 x 0.39 = 3.4 lbs. Scaling the data for the Red Dean bare charges at 45° to the axis (curves A in Figures 9-10) by the cube root of this weight the curves shown in Figures 11-12 have been obtained. The mean experimental values of peak pressure and positive impulse recorded at a distance of ten feet during the actual Blue Jay firing are also plotted in Figures 11-12. It will be seen that the experimental values are in good agreement with the curves predicted by the Red Dean bare charge results.

3.2 Comparison of experimental values of equivalent bare charge weight with empirical formulae

By comparing the blast from bombs and munitions of various charge to total weight ratios several empirical formulae have been suggested for calculating an approximate 'equivalent bare charge' weight value.

Fano[4], using data based on a study by Gurney[5] of the partition of energy of a detonating charge between blast and fragments, deduced the following formulae relating the equivalent bare charge weight W_e to the actual charge weight W.

$$W_e = \left\{0.2 + \frac{0.8}{1 + \frac{2M}{C}}\right\} W \qquad \text{.......(1)}$$

where $\frac{M}{C}$ is the ratio of weight of metal to the weight of explosive in the cylindrical section of the bomb, i.e. neglecting the weight of the casing at the ends.

This equation was later found to predict values which were too low and Fisher[6], using additional experimental evidence suggested three formulae. These were applicable to the three main types of weapons namely, light cased, general purpose and semi armour piercing bombs. For the case of low charge to total weight ratio bombs (S.A.P.) the formula which gave the best agreement with experimental work using a positive impulse criterion was

$$W_e = \left\{0.2 + \frac{0.8}{1 + \frac{M}{C}}\right\} W \qquad \text{.......(2)}$$

Fisher also found that to obtain results which correlated with peak pressures the right hand side of equation 2 should be multiplied by the factor 1.19. However, no account was taken of the nature of the explosive filling.

An extensive survey was also made by Warren[7] based on British experiments. His general conclusions were that for the non-aluminised explosive RDX/TNT 60/40 the Gurney-Fano expression of equation 1 was adequate to predict 'equivalent bare charge' weights using a criterion of positive impulse but for peak pressure the following equation gave better resulta.

$$W_e = \left\{ 0.4 + \frac{0.6}{1 + \frac{2M}{C}} \right\} W \qquad \ldots\ldots\ldots(3)$$

Further, for the aluminised explosive Minol 2 he suggested the following expression for both peak pressure and positive impulse.

$$W_e = \left\{ 0.55 + \frac{0.45}{1 + \frac{2M}{C}} \right\} W \qquad \ldots\ldots\ldots(4)$$

In Table 3 below the values of 'equivalent bare charge' weights calculated for the Red Dean warhead using the formulae above, are compared with those deduced by direct experiment. The weight of the rod in this warhead is 56 lbs. and the weight of the perspex liner 16.25 lbs. and the combined weight of these has been used for the value M in the ratio $\frac{M}{C}$.

The weight of the ends of the charge has been ignored.

TABLE 3

	Present Experi-ments	Equation 1	Equation 2	Equation 3
Impulse 'equivalent bare charge'	10	8.3	10.6	-
Pressure 'equivalent bare charge'	10	8.3	11.6	12.6

It is observed that equation 2 compares best with experiment.

3.3 Measurements normal to axis of Red Dean bare charges

The mean scaled values of peak pressure and positive impulse measured for this orientation are given in Table 4 in the Appendix. These values have been plotted in Figures 13 and 14 and curves of best fit drawn by eye through them. A comparison of these curves with those obtained from measurements at 45° to the charge axis show that peak pressures are approximately 30% higher at the nearer distances but correspondingly lower further out. Positive impulses however, are lower over the whole range.

This data may now be used to predict the blast parameters in the equatorial plane of the Red Dean and Blue Jay warheads by using the 'equivalent bare charge' weights of these weapons established in para. 3.1 above and applying the normal scaling laws. Thus by scaling the curves of Figures 13

and 14 by the cube root of 10 and 3.4 lbs. the curves of peak pressure and positive impulse as functions of distance for the Red Dean and Blue Jay warheads are obtained. These are shown in Figs. 15-16. Given also, in Figure 17, is the curve of positive duration vs distance for both weapons. Hence for trials in which these warheads have been used the parameters can be picked off at the appropriate stand-off distance. Extrapolation of these curves, if necessary, should be viewed with reserve.

3.4 Discussion of results

The results obtained from the Blue Jay warhead firing, given in the Appendix, indicate a reasonable degree of symmetry in the blast wave about the charge. There is no doubt that a high order detonation was achieved in the three C.R. warhead trials in which blast measurements were made.

It can be seen that an existing empirical formula gives a fair approximation to the 'equivalent bare charge' weight of these C.R. warheads. The degree of correlation is not surprising as the geometry of the C.R. warhead approximates to the geometry of the bombs used to provide the data on which the empirical equation is based. The results show also the dependence of the 'equivalent bare charge' weight on distance from the charge although where the variation is gradual, as in the present case, an average value determined over a range of distances will not predict results seriously in error.

It is also important that adequate bare charge data is available on the variation in blast parameters with charge shape and orientation if the predicted values of pressure and impulse using the normal scaling laws are not to be misleading. As the results indicate, the variation between the peak pressures measured normal and at 45° to the axis of the Red Dean bare charge is the reverse to that observed with right circular cylindrical charges[8] To illustrate this point further Figures 18 and 19 have been prepared to show the comparison of the blast from the Red Dean bare charge and for some other charge shapes for which data exists. All the curves have been drawn for a common weight of explosive (25.75 lbs.) and refer to measurements in the equatorial plane of the charge.

4. CONCLUSIONS

From the results presented in this memorandum the following conclusions have been drawn.

(a) The 'equivalent bare charge' weight of the Red Dean C.R. warhead is 10 lbs. RDX/TNT 60/40 for both peak pressure and positive impulse.

(b) The equivalent bare charge weight of the Blue Jay C.R. warhead is 3.4 lbs. RDX/TNT 60/40 for both peak pressure and positive impulse.

(c) The empirical equation which gives the best agreement with experiment for the C.R. warheads used in the experiments is

$$W_e = \left\{ 0.2 + \frac{0.8}{1 + \frac{M}{W}} \right\} W$$

where W_e is the 'equivalent bare charge' weight, W is the actual explosive weight and M is the combined weight of rod and liner.

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TABLE I

Results of blast measurements made at 45° to the axis of a 'Blue Jay' continuous rod warhead. Explosive weight W = 8.81 lb. RDX/TNT 60/40.

Gauge Position		Peak Pressure (psi)	Impulse I (lbs.m.secs/sq.in)	Duration τ (m.secs)	Shock transit time* T (m.secs)
	1	22.59	16.53	2.04	3.62
All gauges 10' from	2	23.94	16.21	2.18	3.62
charge	3	21.34	15.24	1.99	3.57
centre	4	24.75	17.20	2.11	3.51
	5	23.29	16.16	2.17	3.42
	6	23.56	15.65	2.13	3.39
	7	21.19	16.45	2.14	3.42
	8	22.28	17.80	2.20	3.51
Mean Value		22.86	16.41	2.13	3.51
Standard Deviation		1.26	0.66	.07	.091

*time from detonation to arrival of the shock at the gauge.

TABLE II

Results of blast measurements made at 45° to the axis of 'Red Dean' continuous rod warheads. Explosive weight W = 25.75 lbs. RDX/TNT 60/40.

Peak Pressure (psi)

Distance R (feet)	15.5 (5.25)	20.5 (6.95)	30.5(10.33)	41 (13.89)
Round 1	20.34 21.04	12.78 12.40	6.28 6.11	4.18 4.49
Round 2	19.33 19.30	11.54 11.33	5.95 5.74	4.24 4.63
Mean Value	20	12.01	6.02	4.39
Standard Deviation	0.85	0.64	0.23	0.21
	Impulse of positive phase I (lbs.m.secs/sq.in)			
Round 1	22.1 21.9	17.65 17.55	13.1 12.8	10.7 10.4
Round 2	22.0 22.0	19.9 -	12.95 13.0	10.4 10.3
Mean Value	22 (7.46)	17.7(6.00)	13 (4.4)	10.5(3.55)
Standard Deviation	.08 .03	.18 .058	.11 .042	.18 .060
	Duration of positive phase τ (m.secs)			
Round 1	2.92 2.80	3.71 3.85	5.47 5.30	6.54 6.39
Round 2	3.10 3.10	4.21 -	5.41 5.64	6.52 6.74
Mean Value	2.98(1.01)	3.92(1.33)	5.36(1.85)	6.55(2.22)
Standard Deviation	.15 .049	.26 .087	.18 .047	.15 .046
	Shock transit time - t(m.secs)			
Mean Value	5.73	9.04	16.3	24.4

N.B: Figures in parenthesis are scaled values, i.e. $R/W^{\frac{1}{3}}$, $I/W^{\frac{1}{3}}$ etc.

TABLE III

Results of blast measurements made at 45° to axis of Red Dean bare charges of 25.75 lbs. RDX/TNT 60/40.

Peak Pressure (psi)

Distance R (feet)	15 (5.08)	20 (6.78)	30 (10.17)	40 (13.55)
Round 1	36.17 36.73	20.12 24.62	10.19 10.57	6.07 6.07
Round 2	37.90 37.57	20.66 23.61	10.53 10.59	6.27 6.23
Round 3	38.71 40.96	21.43 25.80	10.89 11.17	6.45 6.48
Mean Value	38	22.71	10.65	6.26
Standard Deviation	1.7	2.38	0.34	0.18
	Impulse of positive phase I (lbs.m.secs/sq.in)			
Round 1	38.45 39.60	31.60 31.69	23.32 23.24	17.94 19.59
Round 2	41.11 40.59	- 34.4	23.77 24.22	18.10 17.88
Round 3	39.34 40.94	- 34.14	25.22 24.38	18.77 17.72
Mean Value	40 (13.55)	32.95(11.17)	24.02(8.15)	18 (6.10)
Standard Deviation	1.05 .35	1.52 .52	1.72 .25	0.42 .14
	Duration of positive phase τ (m.secs)			
Round 1	3.12 3.14	3.72 4.09	5.95 5.89	7.36 7.15
Round 2	3.3 2.92	- 4.20	6.13 6.16	7.5 7.39
Round 3	2.86 2.95	- 4.1	6.26 5.93	7.5 6.75
Mean Value	3.04(1.03)	4.03(1.37)	6.05(2.05)	7.27(2.47)
Standard Deviation	.16 .06	0.21 .07	0.15 .05	0.29 .1
	Shock transit time (m.secs)			
Mean Value	4.7	7.4	14.2	21.7

N.B.: Figures in parenthesis are scaled values.

TABLE IV

Results of blast measurements made normal to axis of Red Dean bare charges of 25.75 lbs. RDX/TNT 60/40.

Peak Pressure (psi)

Distance R (feet)	15 (5.08)	20 (6.78)	30 (10.17)	40 (13.55)
Round 1	52.03 48.40	21.40 27.85	6.54 7.15	4.20 4.18
Round 2	47.36 -	18.37 23.60	6.22 6.73	4.28 4.21
Round 3	53.99 53.94	23.52 26.47	6.54 6.88	4.16 4.17
Mean Value	51.14	23.54	6.68	4.20
Standard Deviation	3.1	3.5	0.32	0.05
	Impulse of positive phase I (lbs.m.secs/sq.in)			
Round 1	36.63 33.15	22.95 26.83	16.55 15.90	10.58 10.37
Round 2	35.93 -	21.75 23.30	17.10 17.98	11.75 12.11
Round 3	33.34 34.50	25.40 26.56	16.26 16.53	11.55 11.55
Mean Value	34.7(11.75)	24.47(8.29)	16.72(5.67)	11.32(3.84)
Standard Deviation	1.5 .53	2.1 .71	.64 .25	.65 .21
	Duration of positive phase τ (m.secs)			
Round 1	2.32 2.22	2.71 3.73	5.83 5.63	6.79 6.83
Round 2	2.30 -	3.69 4.18	6.23 6.23	7.23 7.05
Round 3	2.53 2.47	2.92 3.22	6.45 6.92	7.29 7.17
Mean Value	2.37(.80)	3.41(1.2)	6.22(2.1)	7.06(2.4)
Standard Deviation	.13 .05	.56 .19	.46 .16	.21 .07
	Shock transit time t (m.secs)			
Mean Value	2.8	5.2	12.2	20.3

N.B.: Figures in parenthesis are scaled values.

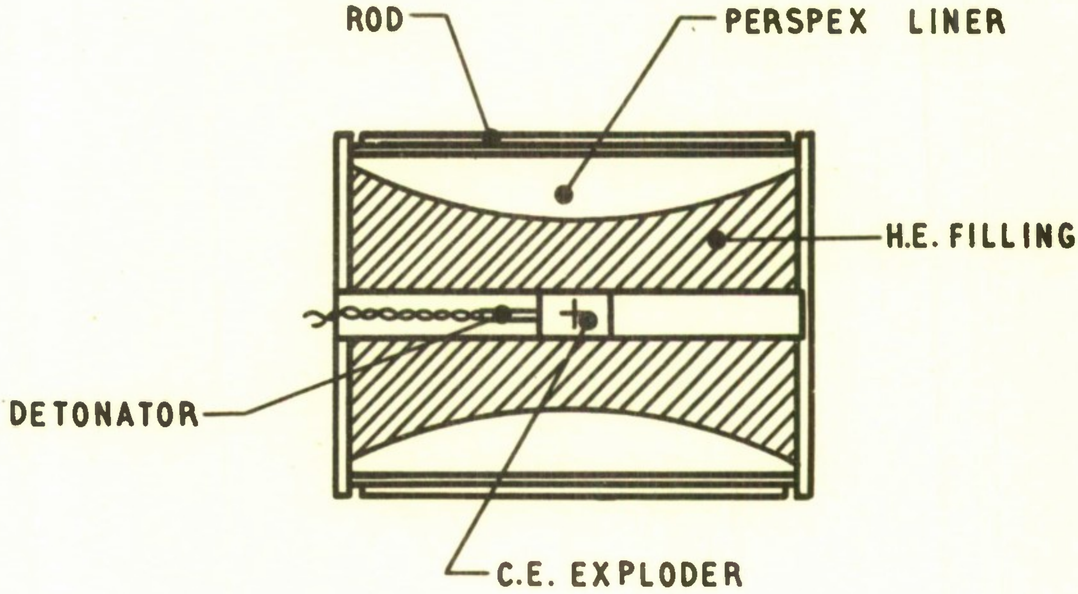


FIG. 1 CONTINUOUS ROD WARHEAD

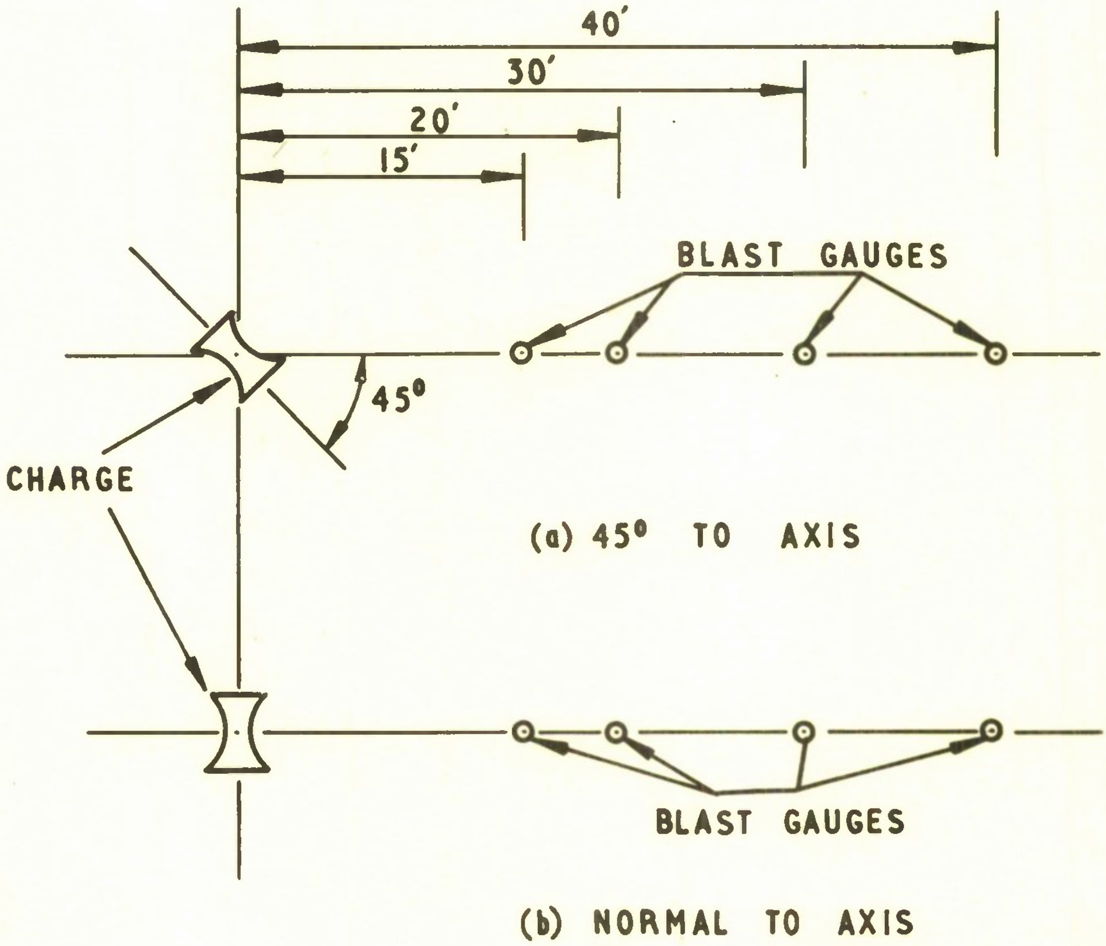


FIG. 2 FIELD LAYOUT FOR RED DEAN BARE CHARGES

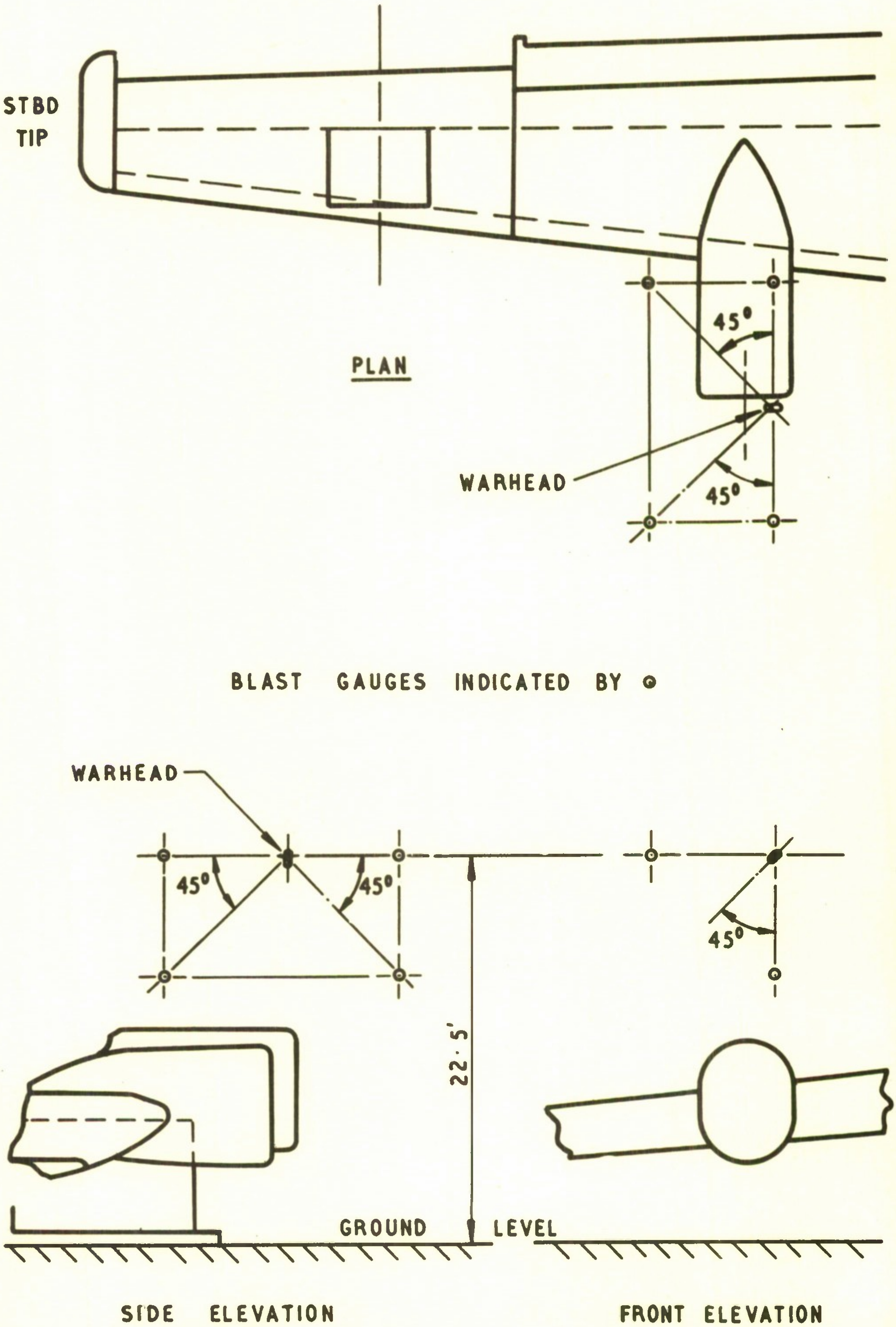


FIG. 3 FIELD LAYOUT FOR BLUE JAY FIRING

FIG. 4

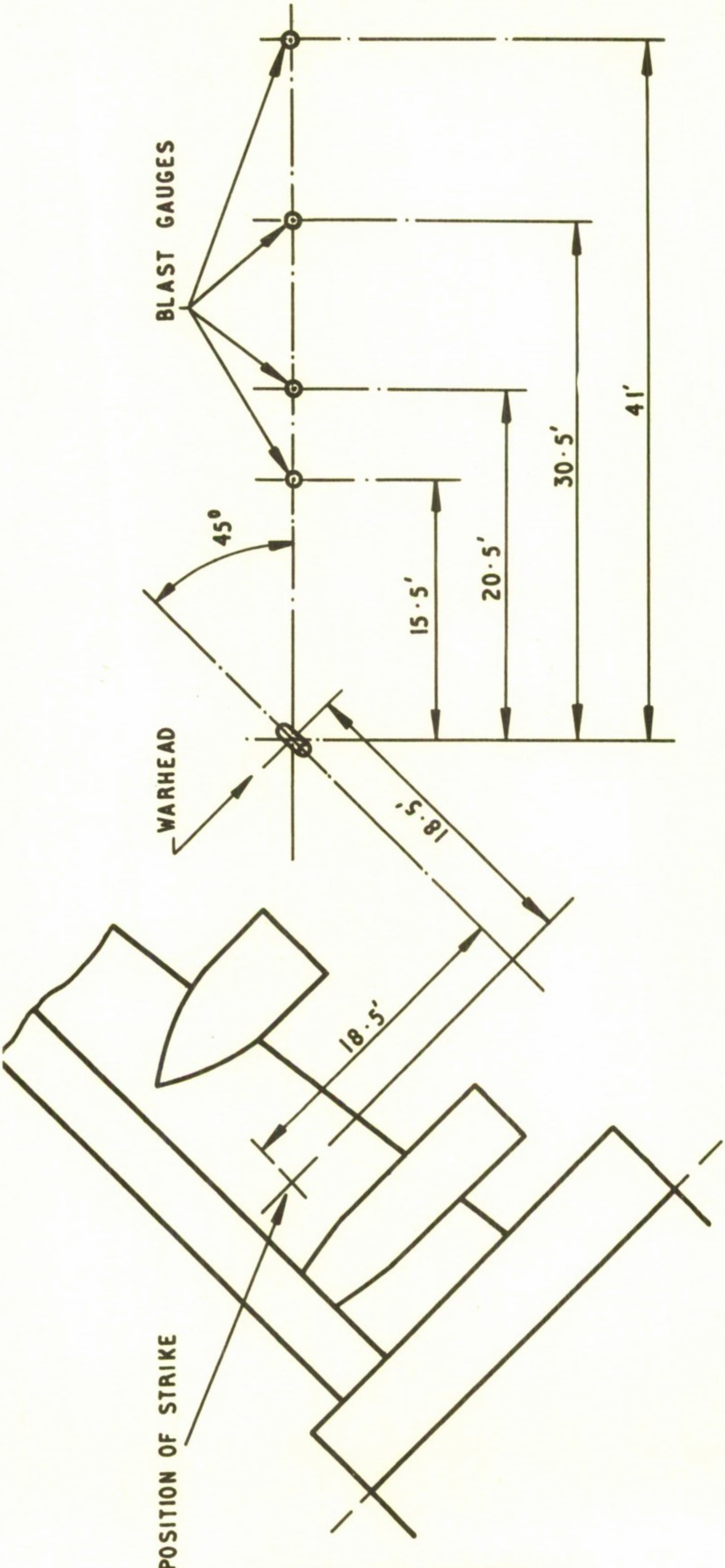


FIG. 4 FIELD LAYOUT FOR 'RED DEAN' FIRING

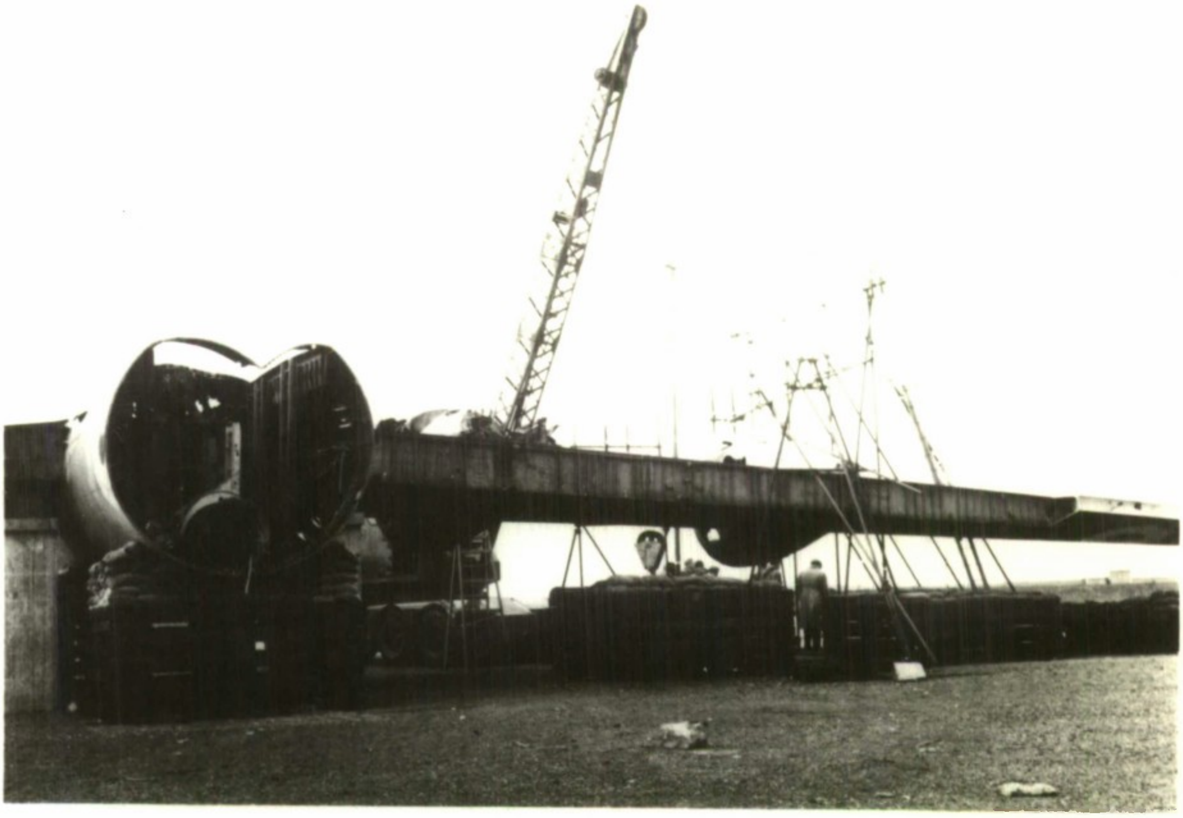


FIG.5 GENERAL VIEW OF FIELD LAYOUT FOR 'BLUE JAY' FIRING

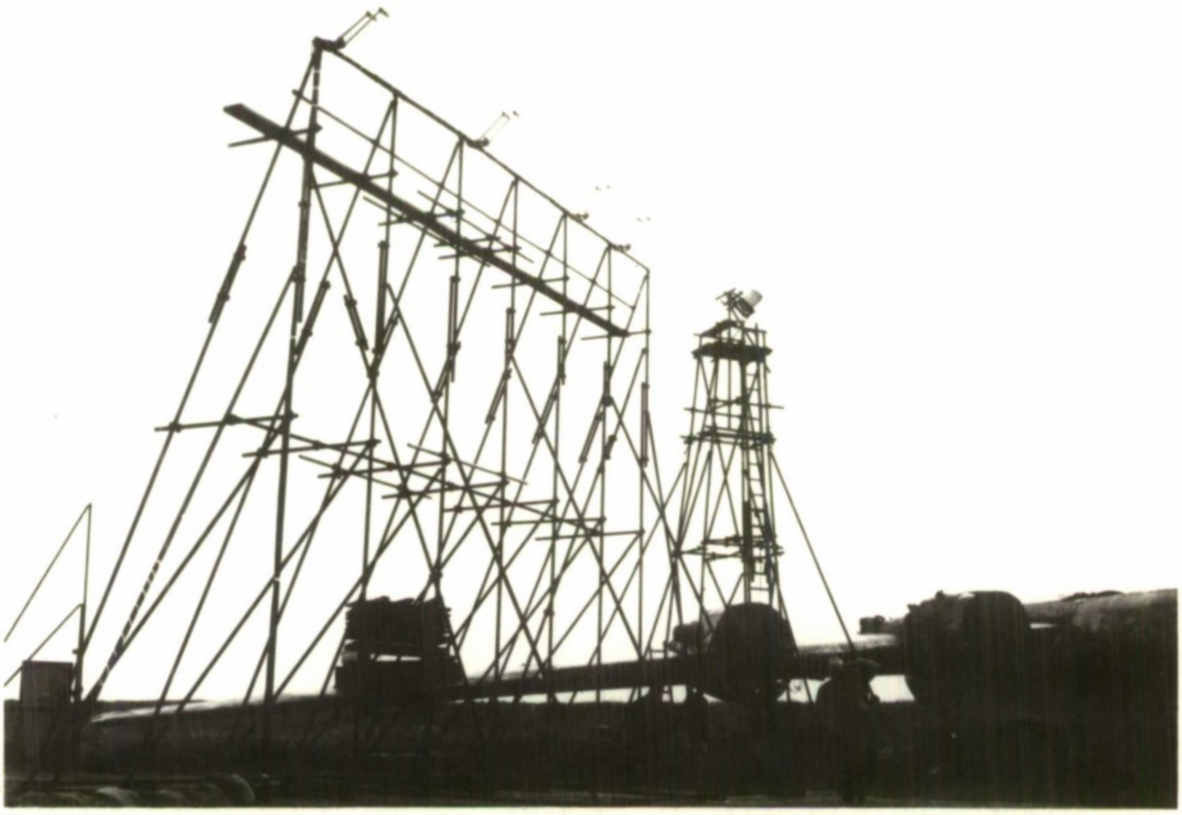


FIG. 6 GENERAL VIEW OF FIELD LAYOUT FOR 'RED DEAN' FIRING

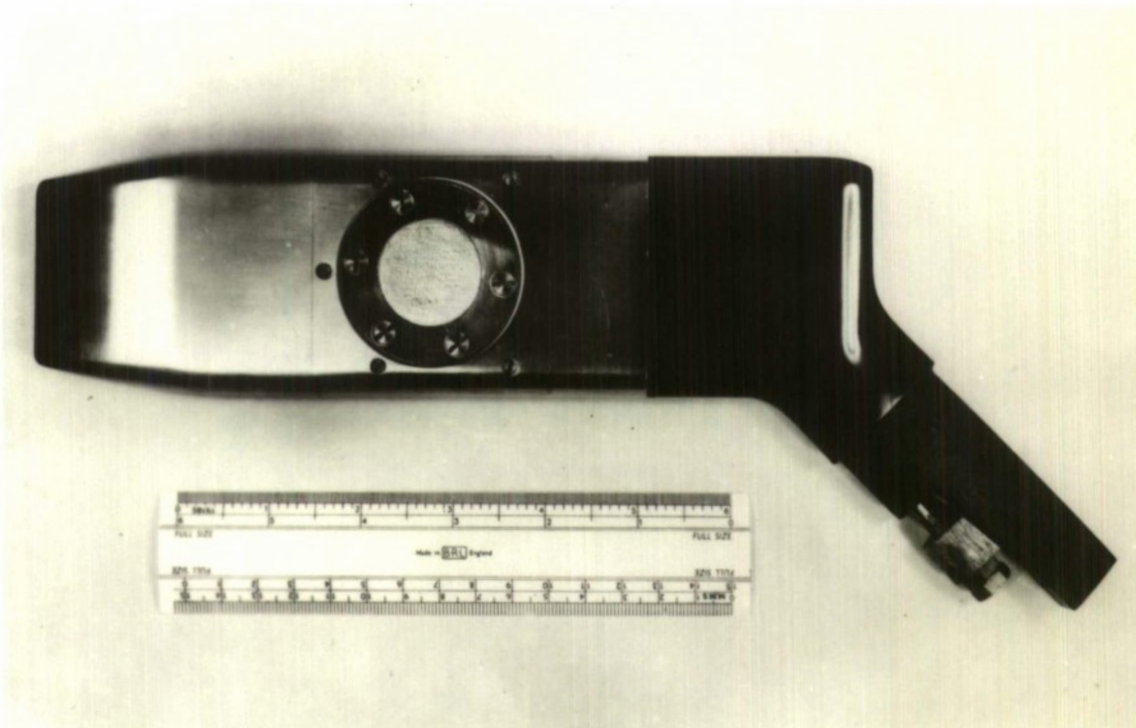


FIG. 7 TYPE H.3, BLAST GAUGE

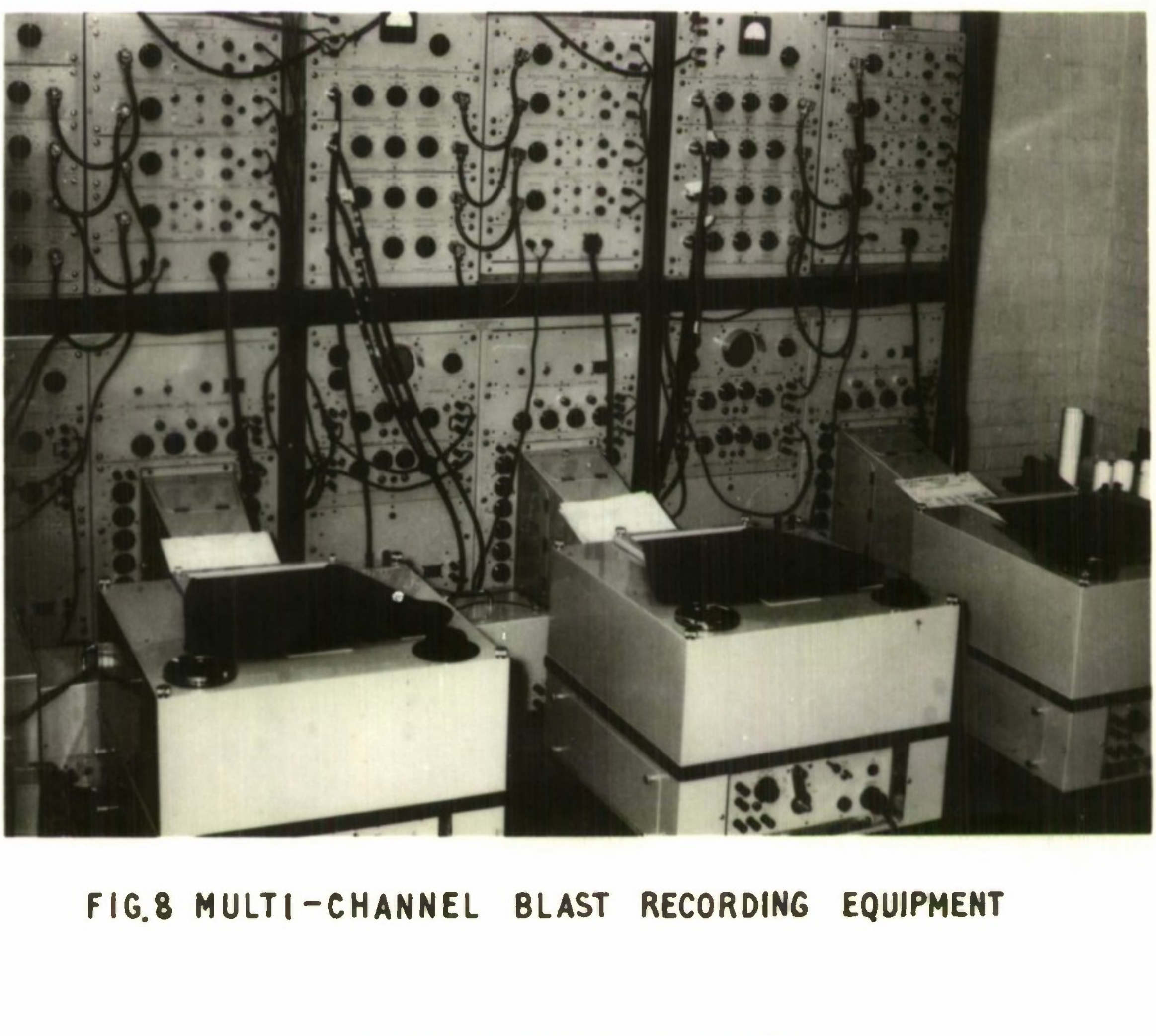


FIG. 8 MULTI-CHANNEL BLAST RECORDING EQUIPMENT

FIG. 9

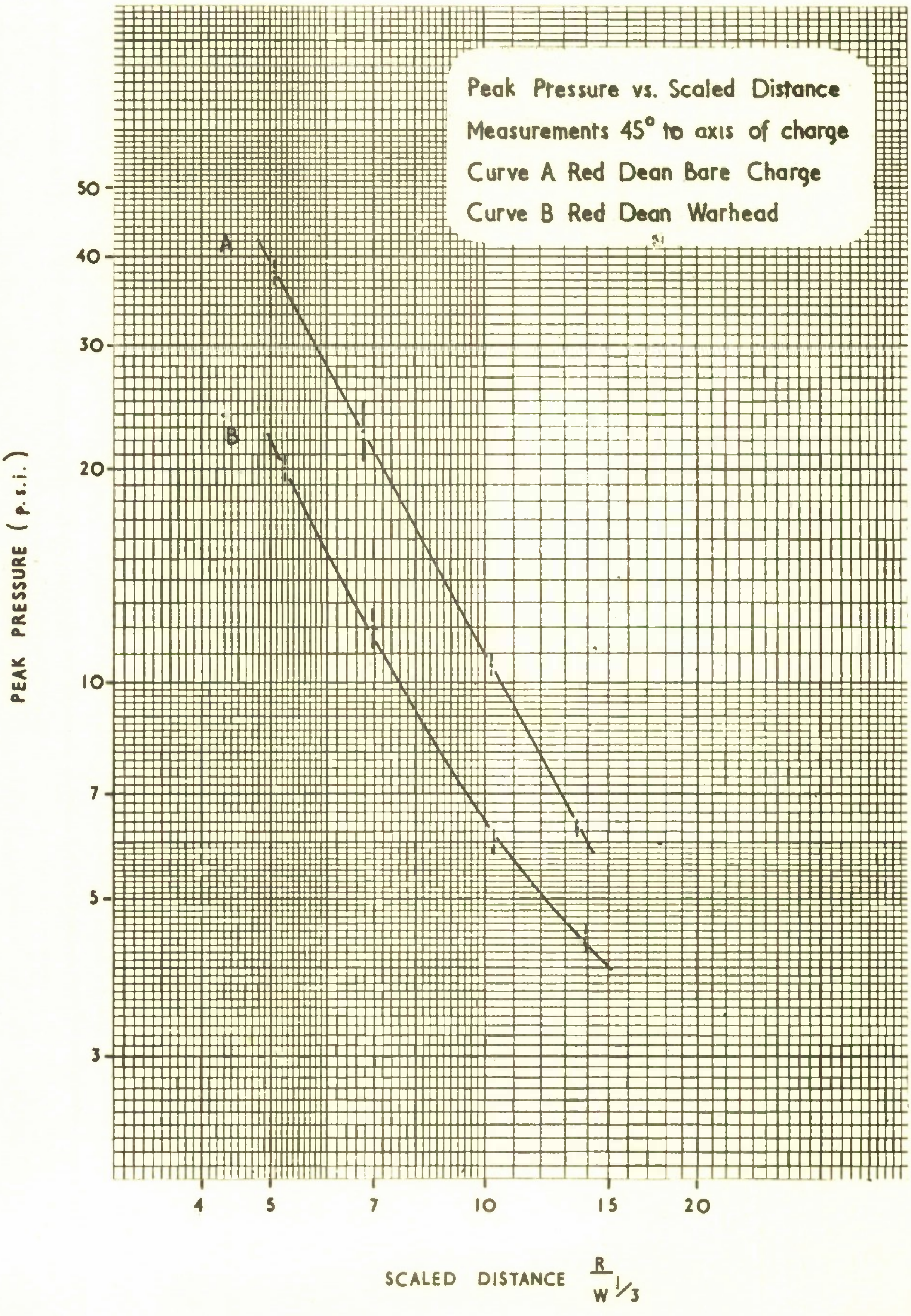

Peak Pressure vs. Scaled Distance
Measurements 45° to axis of charge
Curve A Red Dean Bare Charge
Curve B Red Dean Warhead
A
B
50
40
30
20
10
7
5
3
PEAK PRESSURE (p.s.i.)
4
5
7
10
15
20
SCALED DISTANCE R / W 1/3

FIG.10

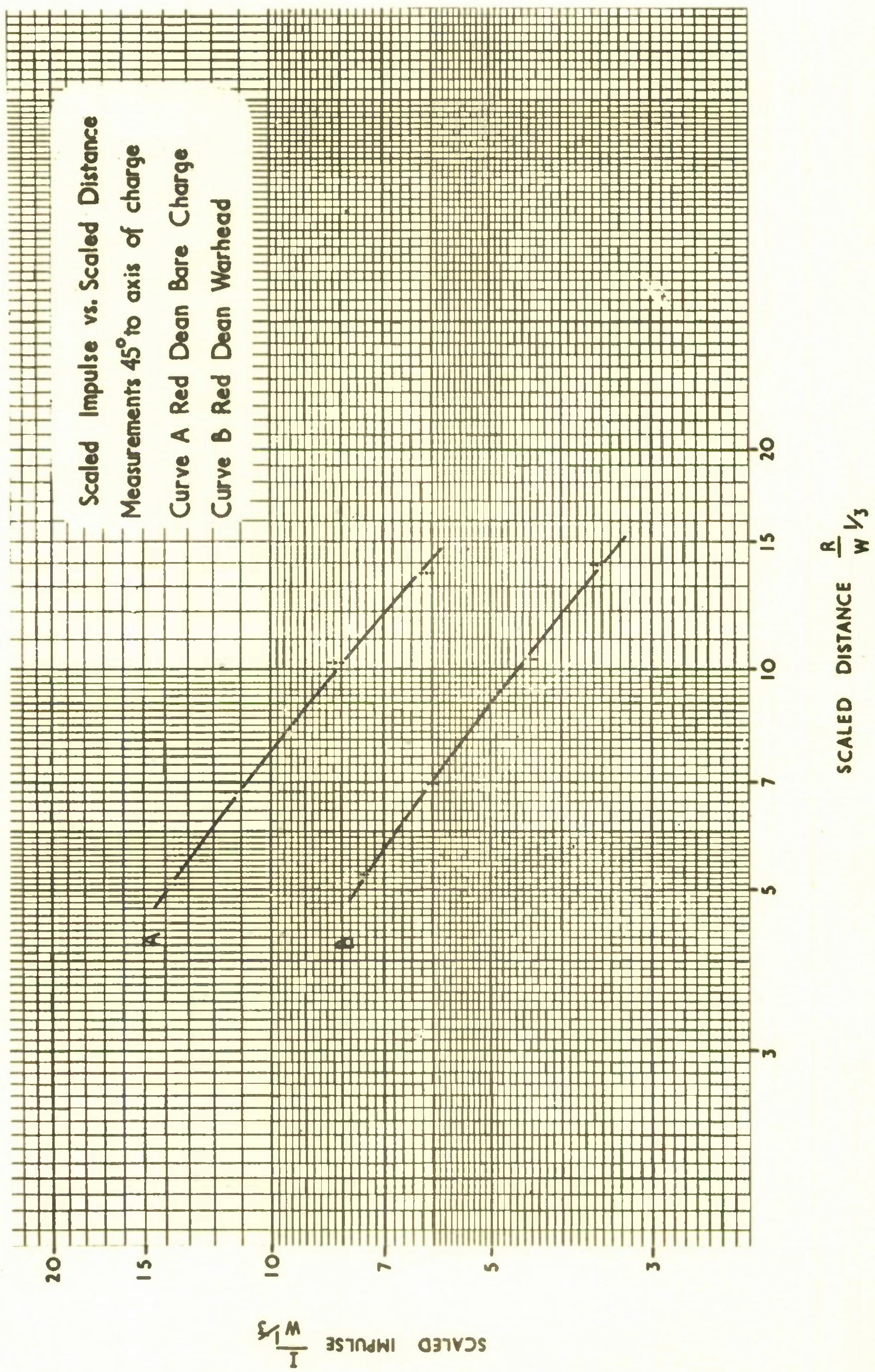

Scaled Impulse vs. Scaled Distance
Measurements 45° to axis of charge
Curve A Red Dean Bare Charge
Curve B Red Dean Warhead
A
B
20
15
10
7
5
3
SCALED IMPULSE $\frac{I}{W^{1/3}}$
3
5
7
10
15
20
SCALED DISTANCE $\frac{R}{W^{1/3}}$

FIG.11

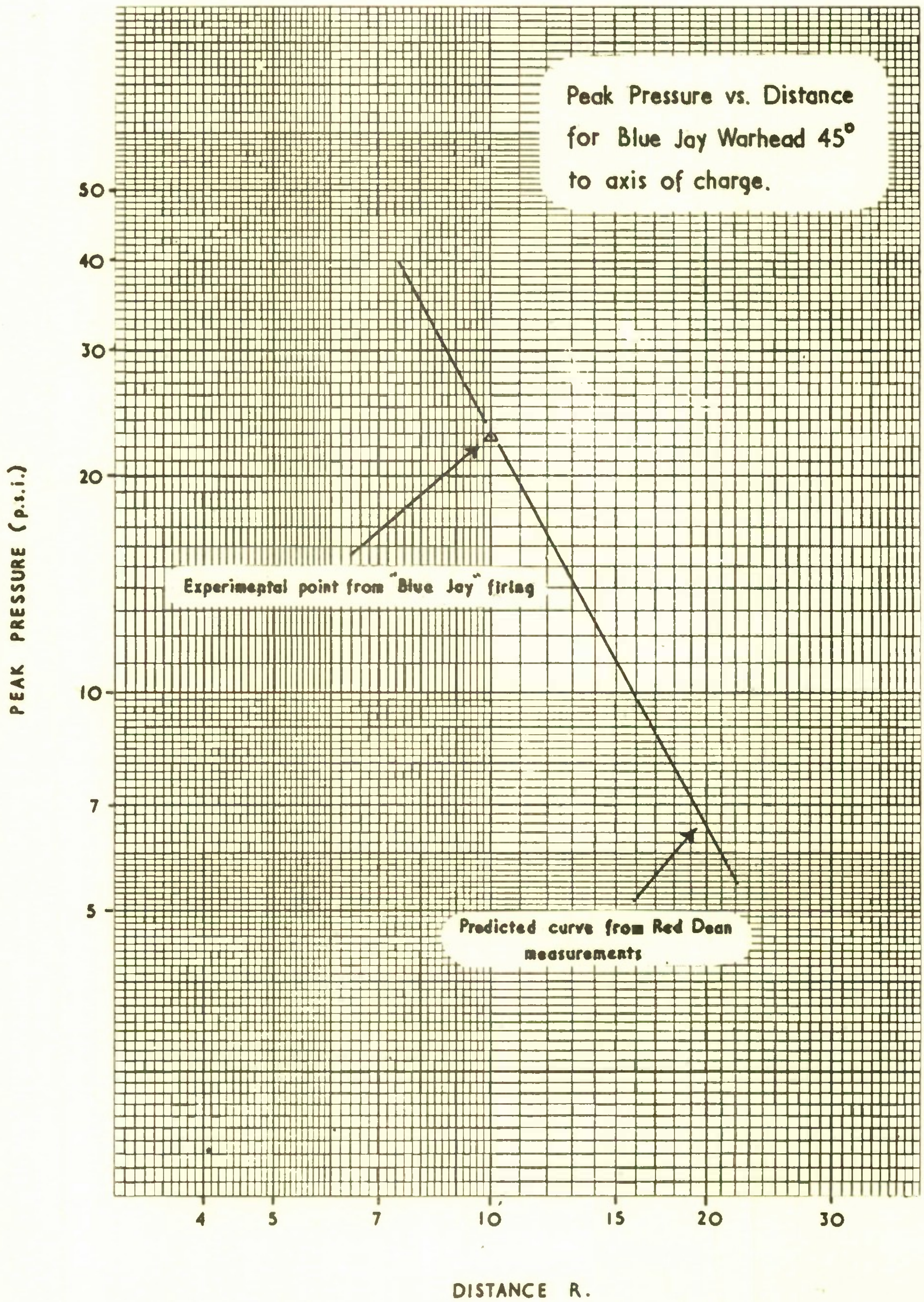
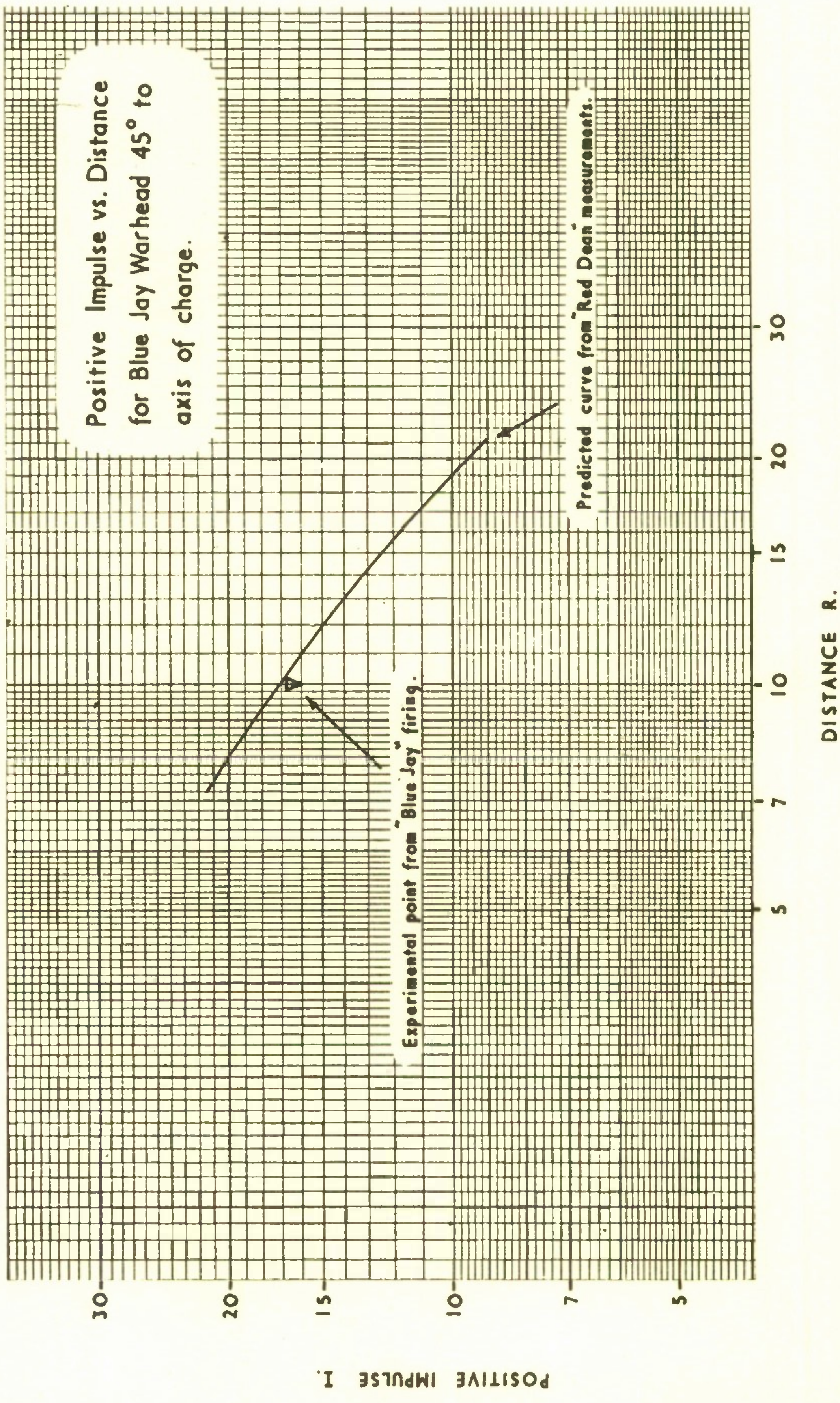

Peak Pressure vs. Distance for Blue Jay Warhead 45° to axis of charge.
PEAK PRESSURE (p.s.i.)
50
40
30
20
10
7
5
Experimental point from "Blue Jay" firing
Predicted curve from Red Dean measurements
4
5
7
10
15
20
30
DISTANCE R.

FIG.12


Positive Impulse vs. Distance
for Blue Jay Warhead 45° to
axis of charge.
Predicted curve from "Red Dean" measurements.
Experimental point from "Blue Jay" firing.
5
7
10
15
20
30
DISTANCE R.
30
20
15
10
7
5
POSITIVE IMPULSE I.

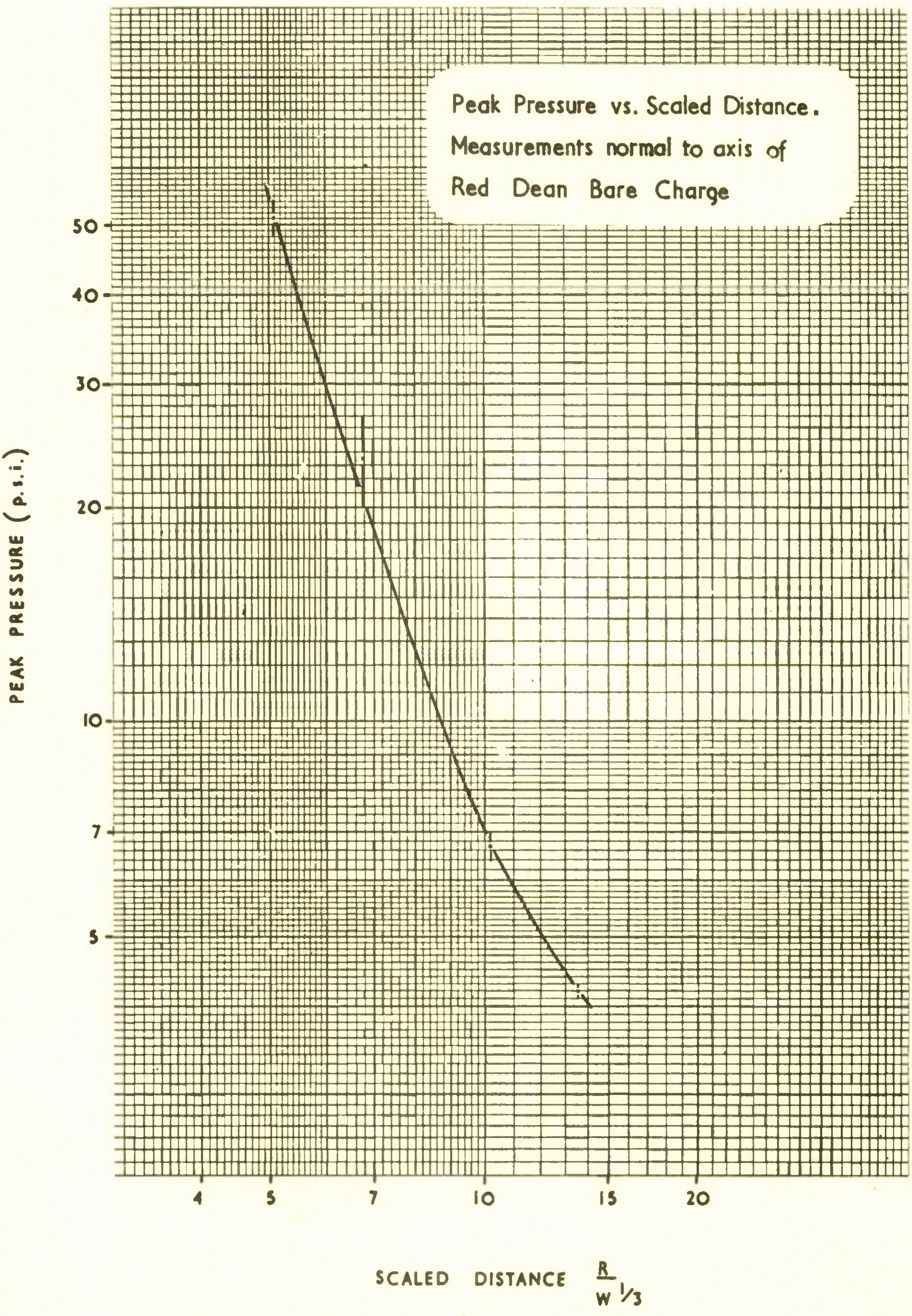

Peak Pressure vs. Scaled Distance.
Measurements normal to axis of
Red Dean Bare Charge
PEAK PRESSURE (p.s.i.)
50
40
30
20
10
7
5
4
5
7
10
15
20
SCALED DISTANCE R/W 1/3

FIG.14

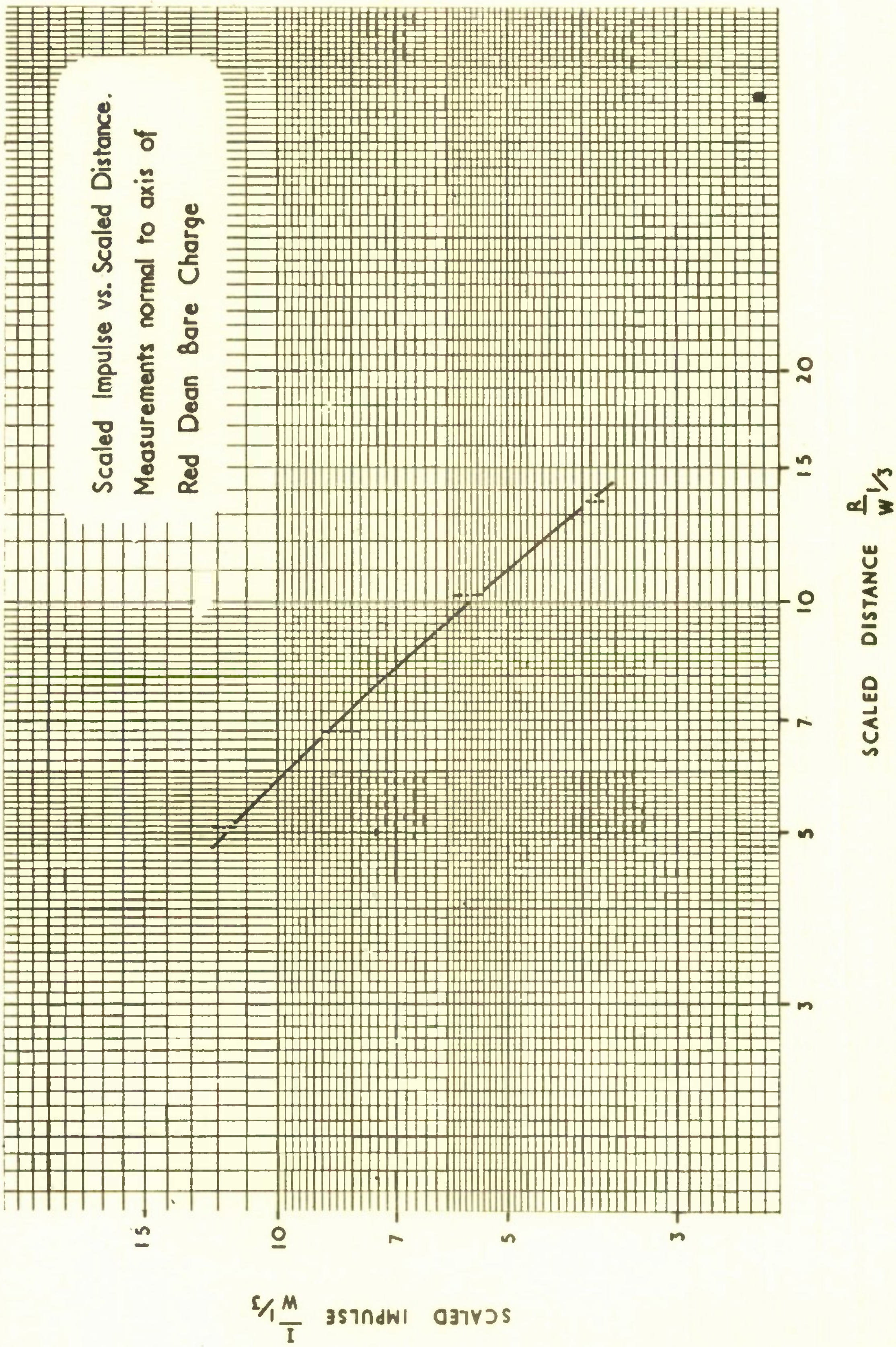

Scaled Impulse vs. Scaled Distance.
Measurements normal to axis of
Red Dean Bare Charge
SCALED DISTANCE $\frac{R}{W^{1/3}}$
3
5
7
10
15
20
SCALED IMPULSE $\frac{I}{W^{1/3}}$
3
5
7
10
15

FIG.15

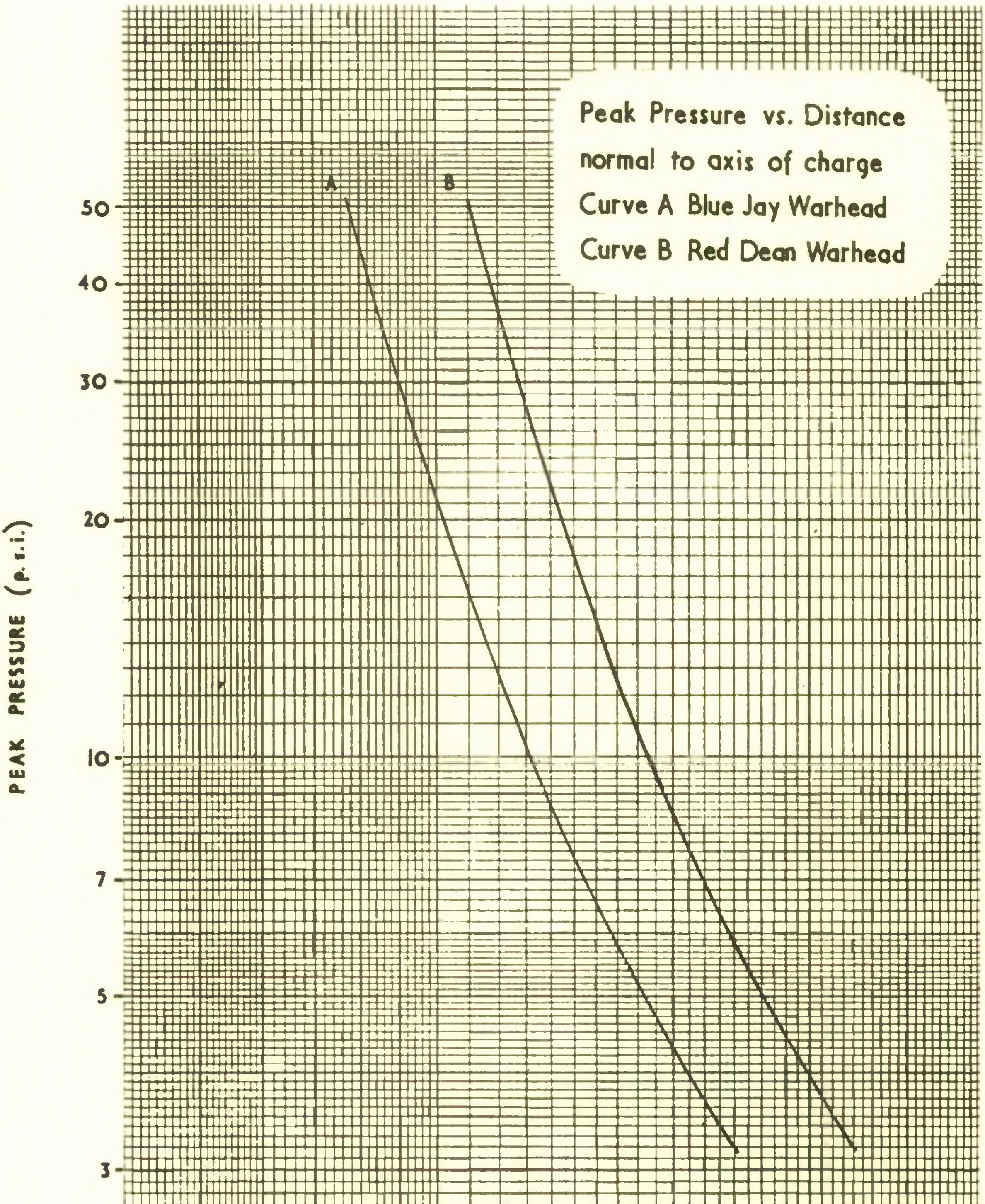

Peak Pressure vs. Distance
normal to axis of charge
Curve A Blue Jay Warhead
Curve B Red Dean Warhead
A
B
50
40
30
20
10
7
5
3
PEAK PRESSURE (p.s.i.)
7
10
15
20
30
40
DISTANCE R.

FIG.16

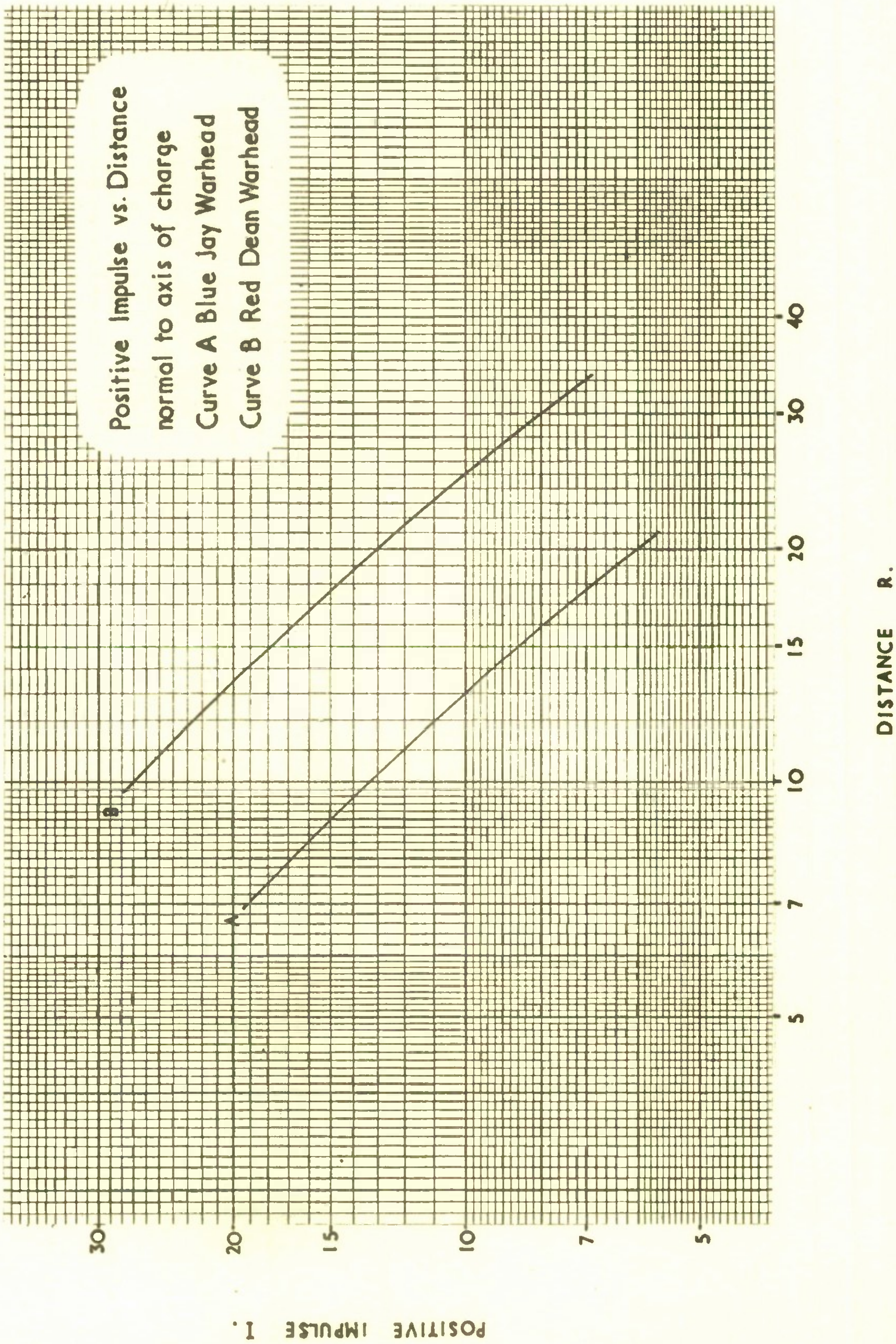

Positive Impulse vs. Distance
normal to axis of charge
Curve A Blue Jay Warhead
Curve B Red Dean Warhead
A
B
5
7
10
15
20
30
40
DISTANCE R.
5
7
10
15
20
30
POSITIVE IMPULSE I.

FIG.17

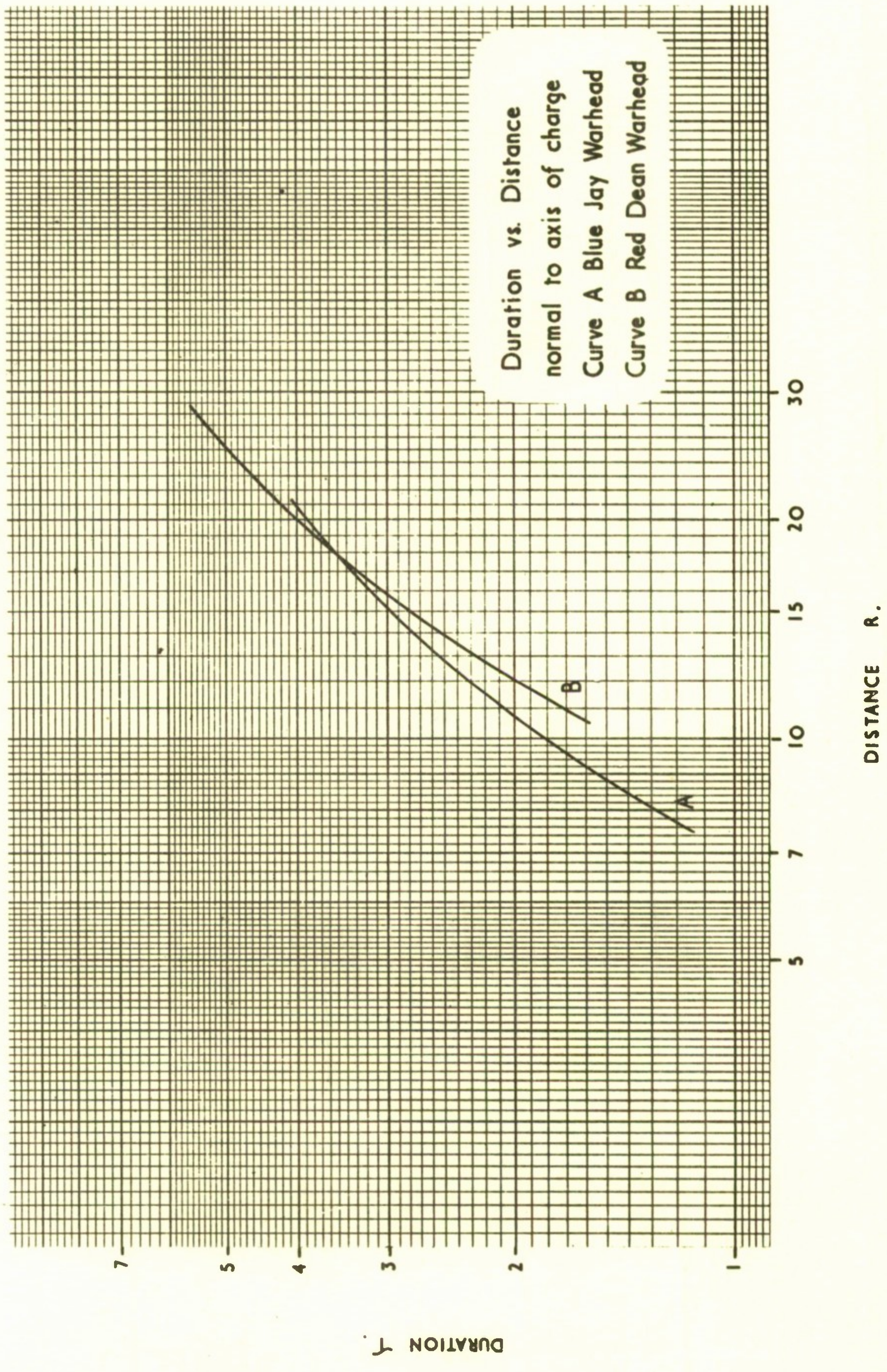
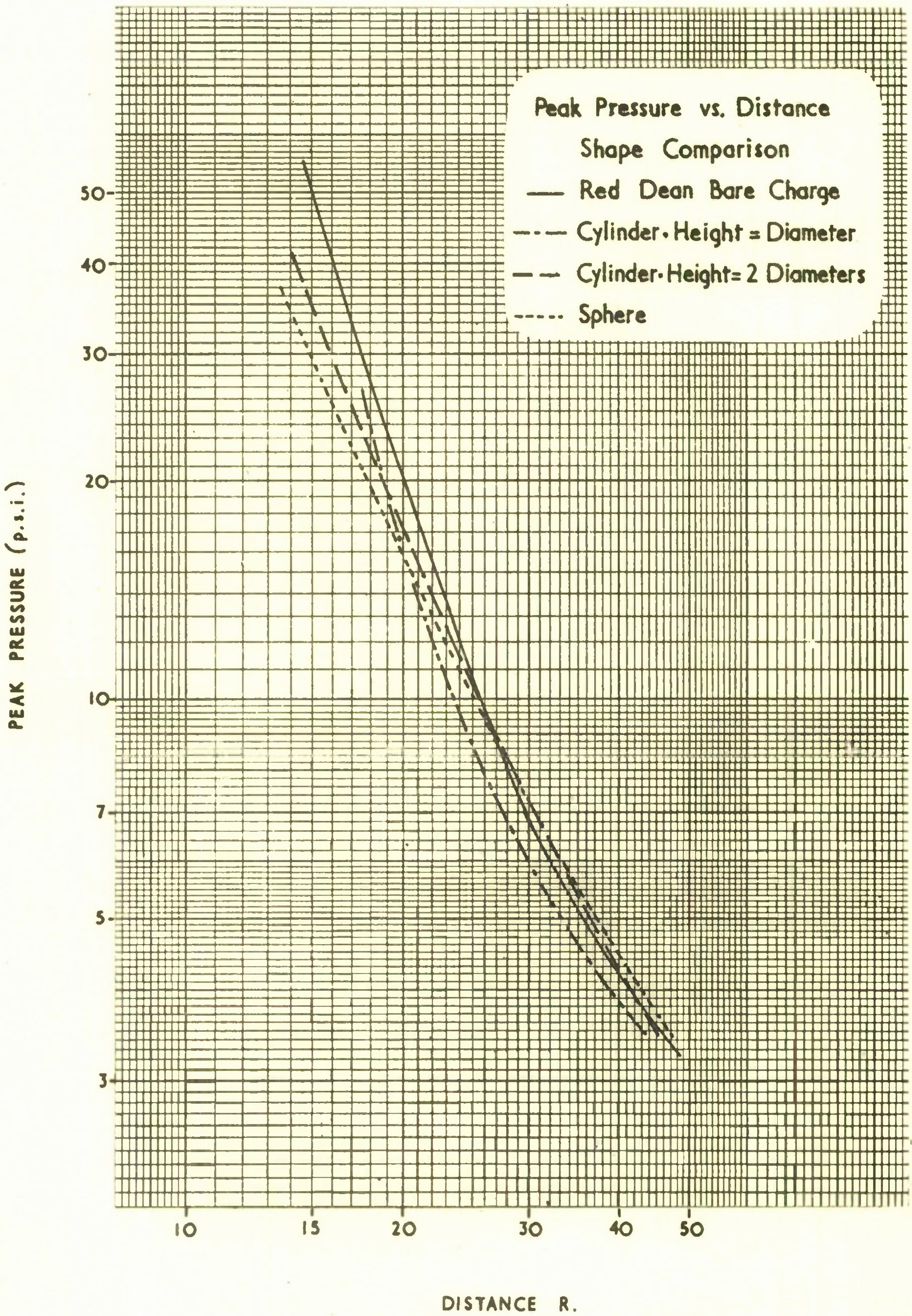
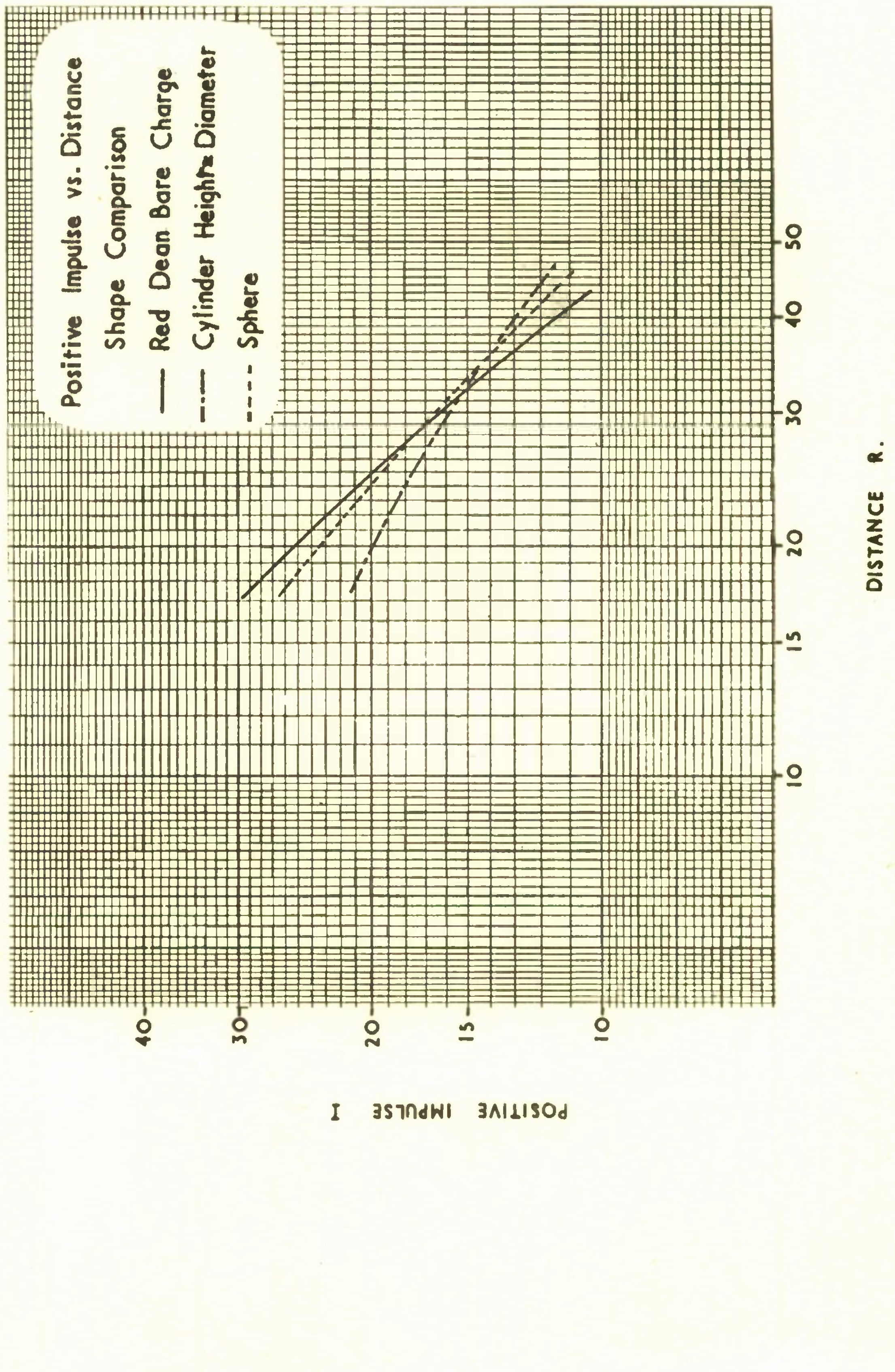

Duration vs. Distance
normal to axis of charge
Curve A Blue Jay Warhead
Curve B Red Dean Warhead
A
B
5
7
10
15
20
30
DISTANCE R.
1
2
3
4
5
7
DURATION T.

FIG.18


Peak Pressure vs. Distance
Shape Comparison
Red Dean Bare Charge
Cylinder. Height = Diameter
Cylinder. Height = 2 Diameters
Sphere
PEAK PRESSURE (p.s.i.)
50
40
30
20
10
7
5
3
10
15
20
30
40
50
DISTANCE R.


Positive Impulse vs. Distance
Shape Comparison
Red Dean Bare Charge
Cylinder Height = Diameter
Sphere
10
15
20
30
40
50
DISTANCE R.
40
30
20
15
10
POSITIVE IMPULSE I

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